Defense Technical Information Center Compilation Part Notice

ADP011736

TITLE: Thermal Receiver Detectable THz Radiation from an InAs Irradiated With 1.04-Micrometers Femtosecond Fiber Laser in a 2-T Permanent Magnet

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: International Conference on Terahertz Electronics [8th], Held in Darmstadt, Germany on 28-29 September 2000

To order the complete compilation report, use: ADA398789

Thermal receiver detectable THz radiation from an InAs irradiated with 1.04-μm femtosecond fiber laser in a 2-T permanent magnet

Hideyuki OHTAKE, Yuji SUZUKI, Nobuhiko SARUKURA, Shingo ONO, Takeyo TSUKAMOTO, Akio NAKANISHI, Seiji NISHIZAWA, Michelle L. STOCK, Makoto YOSHIDA and Heirich ENDERT

Abstract **– Thermal receiver detectable THz radiation is generated from an InAs irradiated with 1.04-μm, 80-fs, 180mW fiber laser in a 2-T field by a compact permanent magnet. The THz radiation is monitored by a pyroelectric thermal receiver that is Deuterated Triglycine Sulfate (DTGS). DTGS operates at room temperature and it neither require time-gating adjustment nor cryogen cooling operation using liquid helium. The size of THz-radiation emitter system becomes almost the same as the conventional notebook computer size including the excitation laser head.**

I. Introduction

There have been numerous necessities for intense, compact, and simple THz(terahertz)-radiation sources which can be applied for sensing [1], imaging [2], and time-resolved spectroscopy [3]. The basic THz-radiation source is photoconductive antenna irradiated with ultrashort laser pulses[5,6]. The average power of THz-radiation from these kinds of antenna has been microwatt level at most, mostly limited by the electric break-down of the photo conductive antennas. An intense, compact, and simple light source is required for applications in sensing or imaging. Concerning intense THz-radiation source, Zhang et al. reported the enhancement of THz-radiation power from GaAs irradiated with femtosecond laser [7]. The enhancement mechanism of THz-radiation power is explained carrier acceleration by magnetic field, therefore, it shows quadratic magnetic field dependence of THz-radiation power up to 0.3 T. We also reported the significant enhancement of THz-radiation power from InAs in a magnetic field irradiated with femtosecond optical pulses, owing to quadratic magnetic field and quadratic excitation intensity dependence of THz-radiation power [8,9]. The advantage to utilise InAs as a THz emitter is approximately one-order higher efficiency of THz-radiation power compared with the GaAs case due to its smaller effective mass [8]. To design practical THz-radiation sources, it is strongly required to examine the scalability of THz-radiation power with this magnetic filed enhancement scheme. Previously, we have reported saturation of THz-radiation power from femtosecond-laser irradiated InAs in a high magnetic field and magnetic field dependence of THz-radiation spectra [9]. After ref. [9], THz-radiation power has been reached sub-miliwatt level to sophisticate magnetic field and incidence angle of the excitation laser [10]. In this presentation, we report thermal receiver detectable THz radiation from an InAs irradiated with 1.04-μm 80-fs, 140-mW fiber laser in a 2-T field by a compact permanent magnet. The THz radiation is monitored by a pyroelectric thermal receiver that is Deuterated Triglycine Sulfate (DTGS). DTGS operates at room temperature and it neither require time-gating adjustment nor cryogen cooling operation using liquid helium. The size of THz-radiation emitter system becomes almost the same as the conventional notebook computer size including the excitation laser head. Compared with the THz-radiation spectrum measured by a bolometer, the same spectrum is obtained even using the DTGS where water vapour absorption lines are clearly observed.

Hideyuki OHTAKE, Yuji SUZUKI, and Nobuhiko SARUKURA are with Institute for Molecular Science, Myodaiji, Okazaki, Aichi 444-8585, JAPAN.
Shingo ONO and Takeyo TSUKAMOTO are with Science University of Tokyo, Kagurazaka, Shinjuku, Tokyo 162-8601, JAPAN.
Akio NAKANISHI is with Sumitomo Special Metal Co., Ltd, Egawa, Shimamoto-cho, Mishima-gun, Osaka 618-0000, JAPAN.
Seiji NISHIZAWA is with JASCO Corporation, Ishikawa, Hachioji, Tokyo 192-8537, JAPAN
Michelle L. STOCK, Makoto YOSHIDA and Heirich ENDERT are with Imra America, Inc. JLO, Kojiritsuki, Hitotsugi-cho, Kariya, Aichi 448-0000, Japan

II. Experiment

The experimental setup is shown in Fig. 1. A 48-MHz repetition-rate mode-locked fiber laser delivers nearly-transform-limited 80-fsec pulses at 1.04 μm. (IMRA Wattlite 1040 nm version)

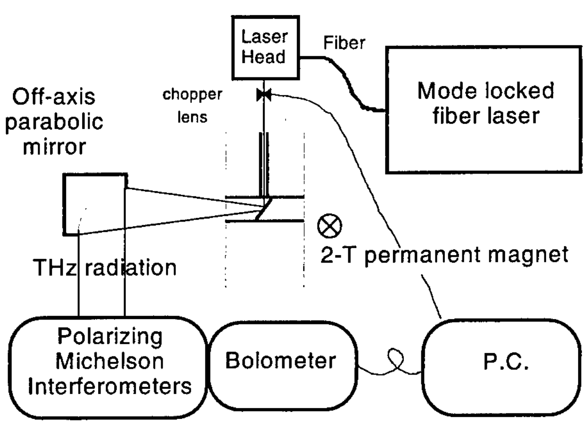

Fig. 1 Experimental setup. Laser beam is focused on the sample with 1-mm diameter.

The mode-locked fiber laser is a completely turn-key system. Compared with previous Femtolite which operates at 1.55 μm, the improvement of Wattlite is significant increase of average power with use of Yb fiber amplifier [11]. The sample is undoped bulk InAs with a (100) surface. The average power for excitation is about 140 mW with 1-mm spot size in diameter on the sample. The sample is undoped bulk InAs with a (100) surface. Since the band gap of InAs at room temperature is about 3.5 μm (0.354 meV), 1.04-μm operating wavelength of Wattlite is short enough to create photoexcited carriers. A small 2 T permanent magnet consists of eight Nd-Fe-B magnet pieces. Each of pieces is magnetised in different ways as shown in Fig. 2. The remanence magnetic field of the Nd-Fe-B material itself is 1.3 T (NEOMAX-44H). Owing to the suitable magnetic circuit design [12], the magnetic field in the center exceeds the remanence magnetic field. The permanent magnet only weighs about 5 kg. The 2-T permanent magnet unit is cylindrical in shape, 128-mm diameter and 56-mm thick, which makes it smaller and much lighter than an electromagnet.

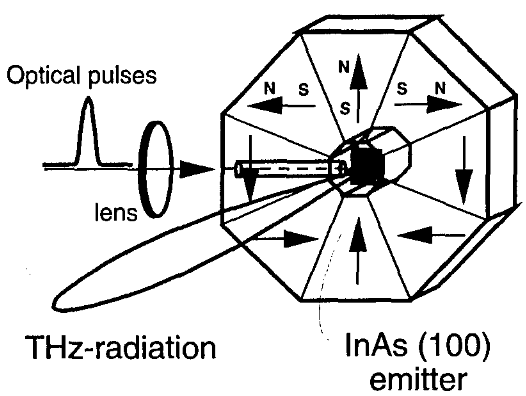

Fig. 2 2-T permanent magnet. The magnet consists of 8 pieces which have different magnetic field directions. The magnetic field reaches 2 T due to the vector sum of magnetic moments.

In the far field, the vector sum of magnetic moments is close to zero. Therefore, the magnet has a very small leak magnetic field owing to the new magnetic circuit. This is an advantage of this radiation source for further system integration. Furthermore, we are planning to increase magnetic field up to 3 T just scaling this design.

III. Results and Discussions

The photograph of THz-radiation system are shown in Fig. 3. The size of THz-radiation system is almost the same as the A4 paper including the laser head, the magnet, and the emitter. This system is much smaller than our previous system [13]. In Fig. 4, we show typical THz-radiation spectra. These spectra are taken by Polarizing Michelson interferometer with a liquid-helium-cooled silicon bolometer and a pyroelectric thermal receiver, respectively. In this condition, the THz radiation can even be observed by a pyroelectric thermal receiver. Unlike time-gated detectors, there is no requirement of timing adjustment and it does not require cryogen cooling for operation. Such a qualitative advance in emitters will certainly widen the application field

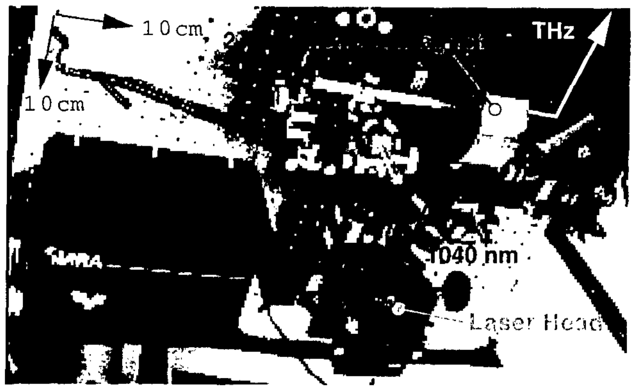

Fig. 3 Photograph of THz radiation system. Laser beam is focused on the sample with 1-mm diameter.

of THz radiation. A typical pyroelectric thermal receiver for detecting THz radiation is deutrated triglycine salfate (DTGS). DTGS is the best material applied as a sensitive element in pyroelectric sensors due to its high pyroelecric coefficient, reasonably low dielectric constant, and best quality factor. DTGS is uniformly sensitive to radiation in wavelength from ultraviolet to far infrared due to its higher Curie temperature. Compared with the THz-radiation spectrum measured by a bolometer, we obtain the same spectrum where water vapour absorption lines are clearly observed as shown by closed blue circles in Fig. 4 [2].

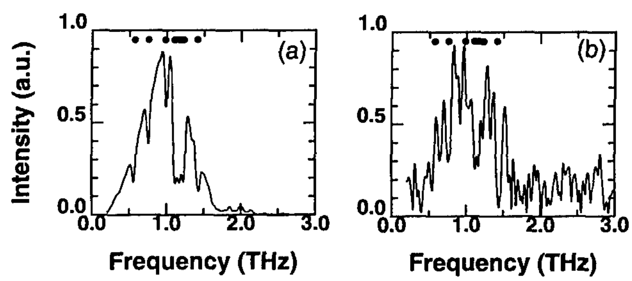

Fig. 4 THz-radiation spectra taken by different detectors.
(a) a liquid-helium-cooled silicon bolometer,
(b) Deutrerated triglycine Salfate (DTGS). In both cases, clear water vapor absorption lines (closed blue circles) are observed.

IV. Conclusion

We have demonstrated thermal receiver detectable THz radiation from an InAs irradiated with 1.04-μm, 80-fs, 180-mW fiber laser in a 2-T magnetic field provided by a compact permanent magnet. The THz radiation is observed by DTGS which operates at room temperature and it neither require time-gating adjustment nor cryogen cooling operation with liquid helium. The size of THz-radiation emitter system is almost the same as the conventional notebook computer size including the excitation laser head.

Acknowledgement

This research was partially supported by Grant-in-Aid for Scientific Research on Priority Areas (11231204) and Grant-in-Aid for Encouragement of Young Scientists (12750046) from The Ministry of Education, Science, Sports and Culture, NEDO Japan Small and Medium

Enterprise Corporation, Creative and Fundamental R&D Program for SMEs, "Research for the Future (RFTF)" of Japan Society for the Promotion of Science (JSPS-RFTF 99P01201), Research foundation for Opto-Science and Technology, and the Sasakawa Scientific Research Grant from The Japan Science Society.

References

1. for example, D. M. Mittleman, S. Hunsche, L. Boivin, and M. C. Nuss, Opt. Lett. **22**, 904 (1997).
2. for example, M. Exter, C. Fattinger, and D. Grischkowsky, Opt. Lett. **14**, 1128 (1989).
3. for example, B. I. Greene, J. F. Federici, D. R. Dykaar, A. F. J. Levi, and L. Pfeiffer, Opt. Lett. **16**, 48 (1991).
4. I. Brener, D. Dykaar, A. Frommer, L. N. Pfeiffer, J. Lopata, J. Wynn, K. West, and M. C. Nuss, Opt. Lett. **21**, 1924 (1996).
5. D. H. Auston, Appl. Phys. Lett. **43**, 713 (1983).
6. D. Krokel, D. Grischkowsky, and M. B. Ketchen, Appl. Phys. Lett. **54**, 1046 (1989).
7. X. -C. Zhang, Y. Lin, T. D. Hewitt, T. Sangsiri, L. E. Kingsley, and M. Weiner, Appl. Phys. Lett. **62**, 2003 (1993).
8. N. Sarukura, H. Ohtake, S. Izumida, and Z. Liu, J. Appl. Phys. **84**, 654 (1998).
9. Hideyuki OHTAKE, Shingo ONO, Masahiro SAKAI, Zhenlin LIU, Takeyo TSUKAMOTO, and Nobuhiko SARUKURA, Appl. Phys. Lett. **76**, 1398 (2000).
10. Shingo ONO, Takeyo TSUKAMOTO, Takayuki YANO, Hideyuki OHTAKE, and Nobuhiko SARUKURA, submitted to Appl. Opt.
11. for example, M. Jiang, G. Sucha, M. E. Fermann, J. Jimnez, D. Harter, M. Dageais, S. Fox, and Y. Hu, Opt. Lett. **24** 1074 (1999).
12. H. Zijlstra, Philips J. Rearch, **40** (5) 259 (1985).
13. Shingo ONO, Takayo TSUKAMOTO, Masahiro SAKAI, Zhenlin LIU, Hideyuki OHTAKE, Nobuhiko SARUKURA, Seiji NISHIZAWA, Akio NAKANISHI, and Makoto YOSHIDA, Rev. Sci. Instrum. **71**, 554-556 (2000).